The Association of BMI and Waist Circumference with Diabetes in an International Context: The CODA (Collaborative Study of Obesity and Diabetes in Adults) Project

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on behalf of the CODA Study Group

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DMICC, Bethesda

RESEARCH QUESTIONS

- There is overwhelming evidence that obesity is strongly associated with type 2 diabetes mellitus (T2DM)
- Which is the better predictor of Type 2 diabetes, WC or BMI?
- What is the shape of the relation?
- Is the association the same in different populations?
- Is the association the same in different age groups, and for both sexes?

PROTOCOL

Multinational collaborative project

Inclusion criteria

- Baseline glucose measurements (fasting glucose and/or oral glucose tolerance test) or incident diabetes
- Baseline measurement of abdominal obesity

METHODS

Analyses restricted to studies with information on both WC and BMI (values > ±4 SDs from the mean in each study were removed)

Age range restricted to ≥ 18 years at baseline

Age- and sex-specific analyses used generalized linear mixed models, with random effects

METHODS

- Age- and sex-adjusted risk ratios for diabetes were predicted from BMI and WC
- Single parameter models:
  - Logistic regression model for baseline data
  - Proportional hazards regression model for follow-up data
  - Estimated absolute risk curves
- Multi-parameter models:
  - Logistic or Poisson predicted in 9 categories
  - Potential bias because each parameter mixes studies differently

Diabetes outcomes (prevalent or incident)

- ADA definition 2003 (FPG ≥ 126 mg/dl)
- WHO definition 1999 (FPG ≥126 mg/dl or plasma glucose ≥200 mg/dl 2-h OGTT)
- Self-reported diabetes (medication, physician diagnosis, etc.)
- Medication per registry
  - Newly diagnosed diabetes: ADA or WHO minus self-report

PROSPECTIVE STUDIES I

Study	Baseline years	Country	N	% women	Age range	Mean FU [years]	WC-BMI Corr	BMI Mean	WC Mean	% newly dx DM	Incident DM rate per 10,000
ARIC	1986-90	USA	15,792	55	44-66	8	0.90	27.6	97.0	4.4	153.0
CARDIA	1985-86	USA	5,115	54	18-30	13	0.89	24.4	77.5	0.4	57.8
ELY	1990-92	UK	1,040	57	40-67	9	0.83	25.8	83.4	-	58.4
FIN-MON	1987,92	Finland	11,997	53	25-64	9	0.88	26.3	86.3	2.1	14.1
FRAMINGHAM	1995	USA	3,197	53	22-79	4	0.88	26.7	88.9	-	65.6
GOTEBORG	1968-70	Sweden	1,462	100	38-61	24	0.85	24.0	73.3	-	32.6
HIROSHIMA	1994-96	Japan	907	52	30-80	4	-	23.5	-	7.4	332.1
IOWA	1986	USA	41,836	100	52-71	10	0.82	26.9	87.9	-	58.9
IRAS	1992-94	USA	1,624	56	39-69	5	0.87	29.4	93.3	10.1	281.0
JACDS	1983-88	USA	658	47	34-75	10	0.87	24.4	86.8	2.9	204.4

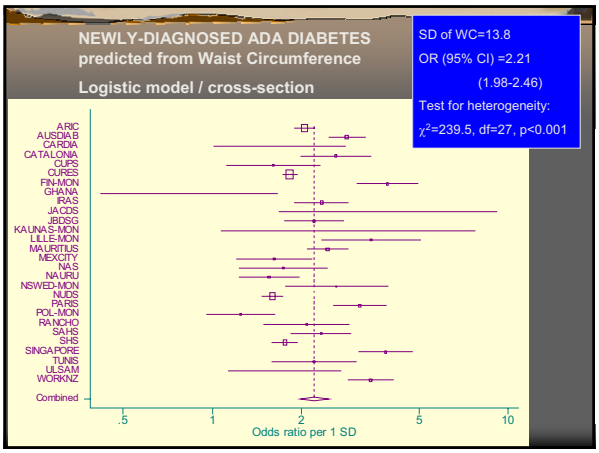
Note: CARDIA incident DM rate per 10,000 based on objective measures (fasting glucose >= 126 mg/dL or meds) = 24.6

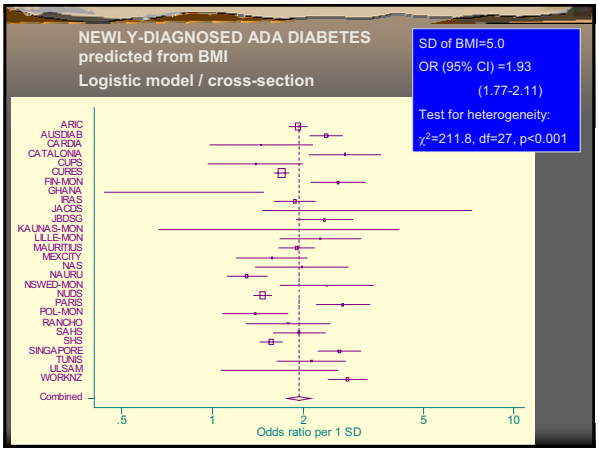
PROSPECTIVE STUDIES II

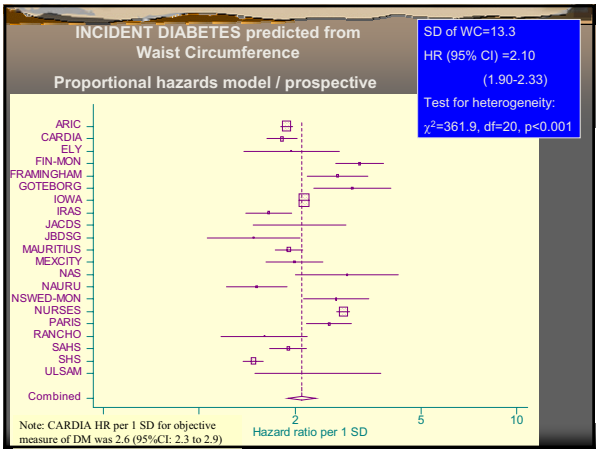
Study	Baseline years	Country	N	% women	Age range	Mean FU [years]	WC-BMI Corr	BMI Mean	WC Mean	% newly dx DM	Incident DM rate per 10,000
JBDSG	1997	Brazil	1,330	47	30-92	7	0.82	24.8	84.5	13.6	416.6
MAURITIUS	1987	Mauritius	5,078	53	25-75	9	0.90	23.5	76.1	5.7	198.0
MEXCITY	1990-92	Mexico	2,282	59	29-67	6	0.86	28.0	96.7	3.1	135.4
NAS	1961-68	USA	2,214	0	21-81	14	0.86	25.8	93.5	5.5	33.6
NAURU	1987	Nauru	868	56	19-81	7	0.89	34.3	97.2	16.5	261.5
NSWED-MON	1986-99	Sweden	6,947	51	25-74	8	0.87	25.5	87.2	1.7	82.9
NURSES	1986-87	USA	52,468	100	39-67	12	0.81	24.6	79.0		30.7
OULU55	1990-91	Finland	831	57	55	7	-	26.5	-	1.4	856.2
PARIS	1967-72	France	7,746	0	43-53	4	0.88	25.4	91.5	2.6	95.4
RANCHO	1984-87	USA	2,480	56	23-96	8	0.82	24.9	85.0	3.2	111.6
SAHS	1979-88	USA	5,158	57	24-69	7	0.85	27.4	90.2	2.8	112.5
SHS	1989-92	USA	4,549	59	44-75	7	0.91	30.8	105.1	14.9	401.7
ULSAM	1970-73	Sweden	2,322	0	50	21	0.86	25.0	87.8	8.8	59.8

CROSS-SECTIONAL STUDIES

Study	Baseline years	Country	N	% women	Age range	WC-BMI Corr	BMI Mean	WC Mean	% with newly dx DM
AUSDIAB	1999-2000	Australia	11,247	55	25-95	0.88	26.9	90.8	2.3
CATALONIA	1994	Spain	2,217	56	29-91	0.74	26.3	89.8	4.4
CUPS	1996-1998	India	1,262	56	20-90	0.80	22.5	76.8	3.6
CURES	2001-2002	India	25,902	51	20-90	0.60	22.4	79.5	7.9
GHANA	1998	Ghana	577	55	25-91	0.87	25.3	83.7	2.2
JORDAN	1996-1997	Jordan	2821	63	17-90	-	29.3	-	1.2
KAUNAS-MON	1992-1993	Lithuania	1,239	51	35-64	0.87	27.6	87.6	0.5
LILLE-MON	1995-1996	France	1,195	50	36-67	0.90	26.5	90.9	3.4
NUDS	1999-200	India	11,215	53	20-96	0.63	23.3	80.5	8.6
POL-MON	1992-1993	Poland	466	53	43-73	0.88	28.0	91.9	3.4
SINGAPORE	1998	Singapore	4,723	54	18-69	0.89	23.5	79.7	4.5
TUNIS	1995	Tunis	862	60	31-93	0.86	28.4	94.3	7.5
WORKNZ	1988-1990	New Zealand	6,577	28	40-78	0.85	27.2	90.8	3.0


NEWLY-DIAGNOSED ADA DIABETES
predicted from Waist Circumference
Logistic model / cross-section
SD of WC=13.8
OR (95% CI) =2.21
(1.98-2.46)
Test for heterogeneity:
χ^2=239.5, df=27, p<0.001
ARIC
AUSDIAB
CARDIA
CATALONIA
CUPS
CURES
FIN-MON
GHANA
IRAS
JACDS
JBDSG
KAUNAS-MON
LILLE-MON
MAURITIUS
MEXCITY
NAS
NAURU
NSWED-MON
NUDS
PARIS
POL-MON
RANCHO
SAHS
SHS
SINGAPORE
TUNIS
ULSAM
WORKNZ
Combined
.5
1
2
5
10
Odds ratio per 1 SD

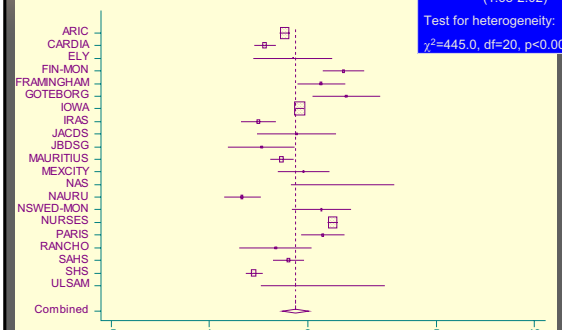

NEWLY-DIAGNOSED ADA DIABETES
predicted from BMI
Logistic model / cross-section
SD of BMI=5.0
OR (95% CI) =1.93
(1.77-2.11)
Test for heterogeneity:
χ^2=211.8, df=27, p<0.001
ARIC
AUSDIAB
CARDIA
CATALONIA
CUPS
CURES
FIN-MON
GHANA
IRAS
JACDS
JBDSG
KAUNAS-MON
LILLE-MON
MAURITIUS
MEXCITY
NAS
NAURU
NSWED-MON
NUDS
PARIS
POL-MON
RANCHO
SAHS
SHS
SINGAPORE
TUNIS
ULSAM
WORKNZ
Combined
.5
1
2
5
10
Odds ratio per 1 SD


INCIDENT DIABETES predicted from
Waist Circumference
Proportional hazards model / prospective
SD of WC=13.3
HR (95% CI) =2.10
(1.90-2.33)
Test for heterogeneity:
χ^2=361.9, df=20, p<0.001
ARIC
CARDIA
ELY
FIN-MON
FRAMINGHAM
GOTEBORG
IOWA
IRAS
JACDS
JBDSG
MAURITIUS
MEXCITY
NAS
NAURU
NSWED-MON
NURSES
PARIS
RANCHO
SAHS
SHS
ULSAM
Combined
2
5
10
Hazard ratio per 1 SD
Note: CARDIA HR per 1 SD for objective measure of DM was 2.6 (95%CI: 2.3 to 2.9)

INCIDENT DIABETES predicted from BMI

Proportional hazards model / prospective

SD of BMI=4.6
HR (95% CI) =1.84
(1.68-2.02)
Test for heterogeneity:
χ^2=445.0, df=20, p<0.001

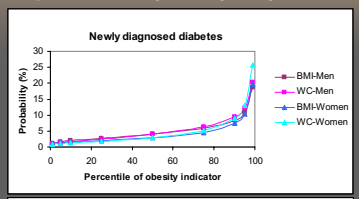


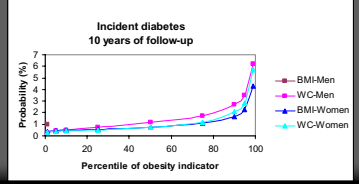
Note: CARDIA HR per 1 SD for objective measure of DM was 1.95 (95%CI: 1.8 to 2.1)

Pooled estimates for BMI and WC association for newly diagnosed and incident diabetes stratified by age group and gender

	BMI		WC			BMI	WC
Newly diagnosed (ADA)	OR	95% CI	OR	95% CI	Test	p	p
18-29	1.31	(1.2, 1.4)	1.58	(1.5, 1.7)	Heterogen..4df	<0.0001	<0.0001
30-44	1.64	(1.6, 1.7)	1.91	(1.8, 2.0)	18-29 vs. 30-44	<0.0001	<0.0001
45-59	1.83	(1.8, 1.9)	2.07	(2.0, 2.2)	30-44 vs. 45-59	<0.0001	<0.0001
60-74	1.96	(1.9, 2.1)	2.16	(2.1. 2.3)	45-59 vs. 60-74	0.0063	0.0209
75+	1.90	(1.8, 2.1)	2.07	(2.0, 2.2)	60-74 vs. 75+	0.4591	0.1519
Men	1.92	(1.8, 2.1)	2.14	(2.0, 2.3)	Men vs. women	0.1182	0.8741
Women	1.80	(1.7, 1.9)	2.16	(2.0, 2.4)			
Incident diabetes	RR	95% CI	RR	95% CI	Test	p	P
18-29	1.59	(1.5, 1.7)	1.83	(1.7, 2.0)	Heterogen, 4df	<0.0001	<0.0001
30-44	1.69	(1.6, 1.8)	1.93	(1.8, 2.1)	18-29 vs. 30-44	0.0129	0.0188
45-59	1.80	(1.7, 1.9)	2.04	(1.9, 2.2)	30-44 vs. 45-59	<0.0001	<0.0001
60-74	1.85	(1.7, 2.0)	2.05	(1.9, 2.2)	45-59 vs. 60-74	0.0002	0.1380
75+	1.83	(1.6, 2.1)	2.01	(1.8, 2.3)	60-74 vs. 75+	0.6279	0.5100
Men	1.75	(1.6, 1.9)	1.95	(1.8, 2.1)	Men vs. women	0.8021	0.1730
Women	1.73	(1.6, 1.9)	2.04	(1.9, 2.2)			

Predicted risk of diabetes for a 50-year old individual based on pooled data, adjusted by study





BMI (kg/m²) distribution

N computed for centers including newly diagnosed diabetes outcome

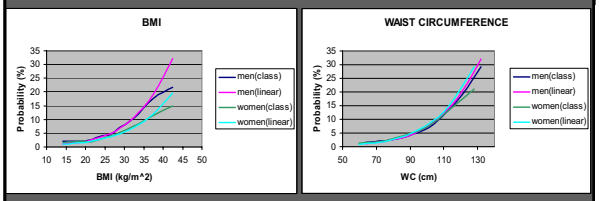
Limits	Men		Women	
	%	N	%	N
10.0-18.4	5.7	3,429	6.8	3,788
18.5-19.9	5.8	3,472	7.4	4,116
20.0-22.9	20.8	12,559	23.4	12,951
23.0-24.9	18.7	11,290	16.3	9,045
25.0-27.4	22.7	13,733	16.6	9,160
27.5-29.9	13.9	8,384	11.3	6,224
30.0-34.9	10.3	6,219	11.9	6,601
35.0-39.9	1.8	1,087	4.4	2,417
40+	0.4	232	1.9	1,047

WC (cm) distribution

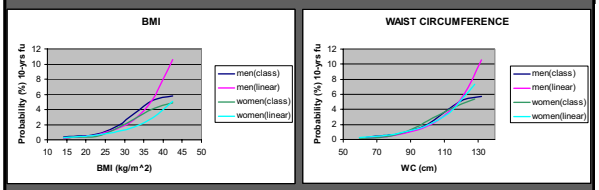
N computed for centers with newly diagnosed diabetes outcome

Men			Women		
Limits	%	N	Limits	%	N
55-71.9	8.9	5,392	55-63.9	5.0	2,774
72-75.9	6.4	3,849	64-66.9	4.9	2,684
76-83.9	18.4	11,101	67-75.9	22.7	12,586
84-87.9	11.7	7,060	76-79.9	11.5	6,347
88-95.9	25.0	15,119	80-87.9	21.7	11,994
96-101.9	14.4	8,724	88-93.9	12.4	6,842
102-115.9	13.0	7,866	94-106.9	15.0	8,314
116-125.9	1.7	1,028	107-118.9	4.9	2,683
126+	0.4	266	119+	2.0	1,125

Absolute % with newly diagnosed ADA diabetes: comparison of single parameter and multi-parameter logistic models



Absolute % with incident diabetes: comparison of single parameter and multi-parameter proportional hazards models



Multiple meta-regression of within-study sex- and age-adjusted ln(OR) or ln(HR) for diabetes per SD of the given obesity indicator, with study-level covariates

	BMI			WC		
Newly diagnosed (ADA)	Estimate	SE	P-value	Estimate	SE	P-value
Prevalence of newly diagnosed (%)	-0.0185	0.0066	0.005	-0.0276	0.0082	0.001
Obesity indicator (mean)	- 0.0105	0.0155	0.496	-0.0027	0.0084	0.742
Age (mean)	0.0119	0.0051	0.242	0.0115	0.0071	0.109

	BMI			WC		
Incident diabetes	Estimate	SE	P-value	Estimate	SE	P-value
Diabetes rate (%)	-0.1214	0.0329	<0.001	-0.1654	0.0374	<0.001
Obesity indicator (mean)	-0.0125	0.0149	0.404	0.0087	0.0062	0.888
Age (mean)	0.0056	0.0036	0.119	0.0029	0.0041	0.481
Follow up years (mean)	0.0038	0.0093	0.686	0.0039	0.0110	0.727

Multiple meta-regression of within-study waist measurement protocol: ln(OR) or ln(HR) for diabetes

	Newly diagnosed (ADA)			Incident Diabetes		
	Estimate	SE	P-value	Estimate	SE	P-value
Difference from zero:						
Narrowest waist (n=3/3)	0.52	0.14	<0.001	0.49	0.13	<0.001
Difference from narrowest:						
Midpoint rib/crest (n=15/8)	0.11	0.16	0.485	0.14	0.16	0.366
Just above crest (n=1/1)	0.47	0.28	0.095	0.31	0.27	0.238
Umbilicus (n=9/9)	0.20	0.17	0.251	0.13	0.15	0.409

Comparison of -2 log likelihood (-2LL) for various logistic models of newly-diagnosed ADA diabetes

	Men	% chg	Women	% chg
Age, Age^2 only	18776		19420	
+ WC	18062	-3.8%	18496	-4.8%
+ Log WC	18092	-3.6%	18504	-4.7%
+ SQRT WC	18074	-3.7%	18496	-4.8%
+ BMI	18130	-3.4%	18602	-4.2%
+ Log BMI	18156	-3.3%	18596	-4.2%
+ SQRT BMI	18138	-3.4%	18592	-4.3%
+ WC/HEIGHT	18072	-3.7%	18484	-4.8%
+ WHR	18454	-1.7%	19138	-1.5%
+ WC, HEIGHT	18034	-4.0%	18460	-5.0%
+ BMI, HEIGHT	18124	-3.5%	18602	-4.2%
+ BMI, WHR	18040	-3.9%	18478	-4.9%

Yellow is 'worst', green is 'best' model by likelihood criterion, amongst models presented

Comparison of -2 log likelihood (-2LL) for various Poisson models of incident diabetes

	Men	% chg	Women	% chg
Age, Age^2 only	11068		51098	
+ WC	10474	-5.4%	47372	-7.3%
+ Log WC	10460	-5.5%	47168	-7.7%
+ SQRT WC	10464	-5.5%	47254	-7.5%
+ BMI	10466	-5.4%	47712	-6.6%
+ Log BMI	10444	-5.6%	47430	-7.2%
+ SQRT BMI	10452	-5.6%	47550	-6.9%
+ WC/HEIGHT	10452	-5.6%	47354	-7.3%
+ WHR	10686	-3.5%	48948	-4.2%
+ WC, HEIGHT	10438	-5.7%	47274	-7.5%
+ BMI, HEIGHT	10466	-5.4%	47710	-6.6%
+ BMI, WHR	10394	-6.1%	46810	-8.4%

Yellow is 'worst', green is 'best' model by likelihood criterion, amongst models presented

CONCLUSIONS

Motivation for problem

Various evidence suggests that visceral fat is a stronger predictor of diabetes than is subcutaneous fat

It would be desirable for screening and prediction to use a measure of obesity that is more specific to visceral fat

Waist circumference is a reasonable candidate, perhaps modified for frame size by height or hip circumference, while BMI intuitively relates to fat generally.

However, the correlation between waist and BMI is about 0.8

Therefore we ask:

Empirically, does waist offer an improvement over BMI in prediction of diabetes?

CONCLUSIONS

Waist circumference and BMI are both strongly and consistently related to diabetes risk

The association is largely similar using

- newly diagnosed ADA
- incident diabetes
- total prevalence (data not shown)
- newly diagnosed WHO criterion diabetes (data not shown)

Even modest overweight is associated with increased risk

Smooth gradient: multi-parameter and single parameter solutions similar (flattening at top end of obesity indicator due to measurement limitations)

Using several different analytic techniques, waist circumference is consistently a *slightly* better predictor of risk diabetes than BMI (note slight attenuation due to differences in waist protocol)

Negligible improvement using height, hip or transforms in model

CONCLUSIONS

Statistically significant heterogeneity between studies

Risk gradients similar for men and women, slightly stronger at older ages

Diabetes prevalence or incidence in the population is inversely related to the diabetes-obesity association, and explain part of the heterogeneity

The answer to the motivating question is "no", waist does not appear to offer substantial advantages over BMI; the two are almost interchangeable in diabetes prediction. Whether there is an interaction between BMI and waist (waist predicts differently for small than large BMI) has not been investigated.

WRITING COMMITTEE

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